THE TACTICAL PLANNING OF AIR CARGO OPERATIONS

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INTRODUCTION

In 1990, the airline industry world-wide has suffered losses in the order of 2,5 billions U.S. dollars, and the outlook for 1991 is even worse. In the past, many airlines have neglected the air cargo's segment of their operations because of its rather small contribution to revenue when compared with passenger traffic. But this is changing rapidly as air cargo's significant contribution to airlines' profits is being recognized. As a result, more airlines will actively compete for a share of the air cargo market. Consequently, more than ever before, airlines must manage their air cargo operations very carefully and come up with tactical operating plans that will allow them to quickly adapt to changes in their environment.

Tactical planning is usually performed over a period of a few months and typically consists in adjusting air cargo operations to seasonal variations in the forecast demand. In this paper, we briefly describe the operations of air cargo within an airline. Next, we examine two interrelated tactical planning problems for air cargo operations: 1) routing freight in a given network of aircraft services, and 2) designing work schedules at air freight terminals. We then propose a model and solution approach to assist airline managers in solving those problems. Finally, we conclude with a discussion of various extensions to our model and future research directions.

1. AIR CARGO OPERATIONS

Airlines operate two types of aircrafts for the purpose of carrying freight: 1) freighters, that are dedicated to carry cargo only, and 2) combination or combi aircrafts that carry both passengers and cargo[1]. Freighters will be used on those routes with sufficient demand for air cargo. Combis' capacity will vary according to the aircrafts' type and configuration. But generally, combis' routes are designed to suit passenger demand.

Some airlines offer different types of cargo services depending upon the level of service (speed and reliability) required by the customer. For instance, priority services will ensure "same day" or "next day" delivery while regular services may take up to a few days according to the origin and destination of the freight. Rates will obviously vary according to the level of service and type of cargo (dangerous goods, live animals, high value items, etc.).

Most of the freight will be carried in containers or ULD's (Unit Load Devices). The remaining cargo will be carried loose in dedicated compartments. There are several types of containers with varying sizes and capacities. Further more, some ULD's are customized to fit only one type of aircraft while others are compatible with a few aircraft types. For example, LD8's can only be used on board of Boeing 767 aircrafts while LD9's can be used on B747, B767 and L1011 aircrafts.

For a better understanding of air cargo operations, Figure 1 shows the typical flow of air shipments. The cycle starts with a demand for air transportation which is seldom known in advance and may vary significantly from one day to another. Demand also varies according to seasonal variations and type of traffic. Freight may be delivered to the origin airport cargo terminal by the shipper himself in containers, on pallets or as loose freight. Or freight is picked up at the shipper's door by freight forwarders and consolidated into containers before delivery to the cargo terminal. Freight is unloaded from the delivery trucks and verified against the information appearing on the shippers' documentation: weight, dimensions, number of pieces, type of freight, and so forth. The carrier determines tariffs and prepares a waybill. The air waybill accompanies the freight and is used to verify it in subsequent handling operations. Next, freight is sorted according to its destination and consolidated into containers. It is then taken to a loading area where it awaits the next aircraft departure along with other containers that were delivered to the origin terminal by freight forwarders.

Aircrafts are not always available for each destination to which freight is addressed. Such freight is consolidated into containers going to intermediate airports where it will be loaded with other cargo going to its final destination. In fact, freight may once again be unloaded, sorted and reloaded at the transfer airport terminal. Sometimes such freight can be kept in its container and moved directly to the next aircraft, which reduces handling and its associated delays and costs. Low volume long-distance shipments may pass through several such intermediate airport terminals.

At the destination terminal, freight is unloaded, verified, tagged and sorted into racks where it awaits pickup by the consignee. Full containers addressed to a single consignee are moved to a loading area for local delivery to (or pick-up by) consignees.

2. TACTICAL PLANNING PROBLEMS

This section describes two interrelated problems that airline managers have to deal with at the tactical or mid-term level of planning: 1) routing freight in a network of combi aircrafts and, 2) designing work schedules at air freight terminals. Next, the relationship between those two problems is examined.

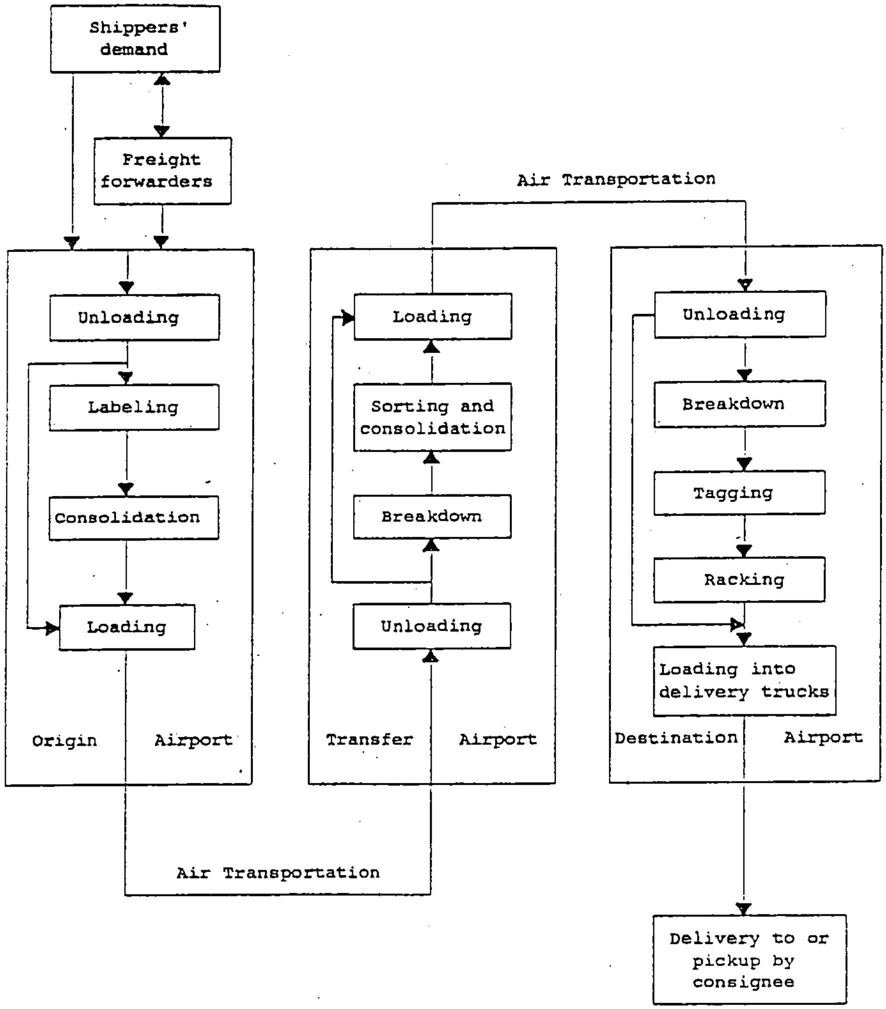


Figure 1: Typical Flow of Air Shipments

2.1. The routing problem

As mentioned earlier, in the airline industry, combi aircrafts' routes are generally designed to satisfy passenger demand. Therefore, one of the main tactical problems facing air cargo managers is the routing of freight in a given network of combi aircraft services. This problem can be defined as the specification of which transportation services (flight segments) will be used to move air freight shipments from origin to destination. This routing is done by minimizing the costs of transportation and handling while satisfying preset service objectives. When routing freight, several factors must be taken into account:

- the various service levels offered by the airlines (e.g., priority or regular);
- the capacity constraints determined by the types of aircrafts used in the network;
- the freight handling capacity and productivity at various airport terminals in the network.

To our knowledge, there is no other reported effort to deal with this particular freight routing problem in the literature, in spite of the abundance of papers published on the topic of operations research applications to the airline industry (Richter, 1989). We have examined some of the literature pertaining to the assignment of passengers to flight schedules (Soumis et al., 1981). But we have found that such models tend (rightfully so) to pay much attention to passenger behaviour patterns that are not necessarily applicable to air freight. In the air cargo literature, much of the more recent research efforts have dealt with cargo space allocation and control problems (Patterson, 1987) and cargo revenue or yield management (Bazaraa, 1990). Those efforts aim at maximizing revenues generated by air cargo operations while we look at how to route freight both effectively (on-time delivery) and efficiently (low-cost solution). However we find our air freight routing problem to be quite similar to the tactical planning problem facing less-than-truckload motor carriers (Roy, 1984; Powell, 1986). Therefore, our proposed model and solution approach which is presented in the next section, will be based upon previous work carried out in the trucking industry (Roy and Delorme, 1989; Roy and Crainic, 1992).

2.2. The work scheduling problem

Another important tactical planning problem is the scheduling of freight handling employees at air cargo terminals. Lately, airlines have been urged to reduce operating costs and this particular area was deemed critical for achieving cost reductions while maintaining customer service levels. The manpower scheduling problem at air cargo terminals can be solved by following two steps. The first one consists of determining the manpower requirements for each job category and for a typical work day in a given planning period. To do this, the following must be taken into account:

- aircrafts' arrivals and departures;
- freight volumes per service class (priority or regular) and for each type of handling unit (container vs loose);
- work standards and productivity measures for each job category;
- working conditions and conventions.

The second step consists of designing work schedules that satisfy the manpower requirements, and comply to all rules and regulations and budget constraints that apply to this problem. The literature is rich with examples of models that can be used to assist in solving that second step (Laporte and Nobert, 1985). One such approach is illustrated in Roy and Ravacley (1982) and will be described in the next section. But determining manpower requirements (the first step) is a more risky process and here, classical industrial engineering and statistical techniques can be put to use. One such example was found in Lebeau and Pilon (1990).

2.3. The relationship between freight routing and work scheduling

Figure 2 illustrates the relationship between our two tactical planning problems. The freight routing problem determines the amount of freight to be handled at each airport in the airline network. This is a major input to the manpower scheduling problem which, at its turn, will influence the freight routing process by determining the proper freight handling costs and capacity at each airport in the network.

3. MODEL AND SOLUTION APPROACH

In this section, we propose a new optimization model for the freight routing problem and a solution approach that leads to a (classical) linear programming model for the work scheduling problem. Then we suggest some post optimization analyses in order to study the relationship between those two problems.

3.1. The Freight Routing Model

Our model is intended to assist air cargo managers in their decision-making process concerning the routing of freight in a given network of combi aircraft services. It is formulated as a linear programming problem, where the amounts of freight, for each origin-destination pair and service level (traffic class), moving on each route (or itinerary) through the network are the decision variables. Their values are determined by minimizing a total system cost (defined below) while satisfying the demand for transportation, specified for

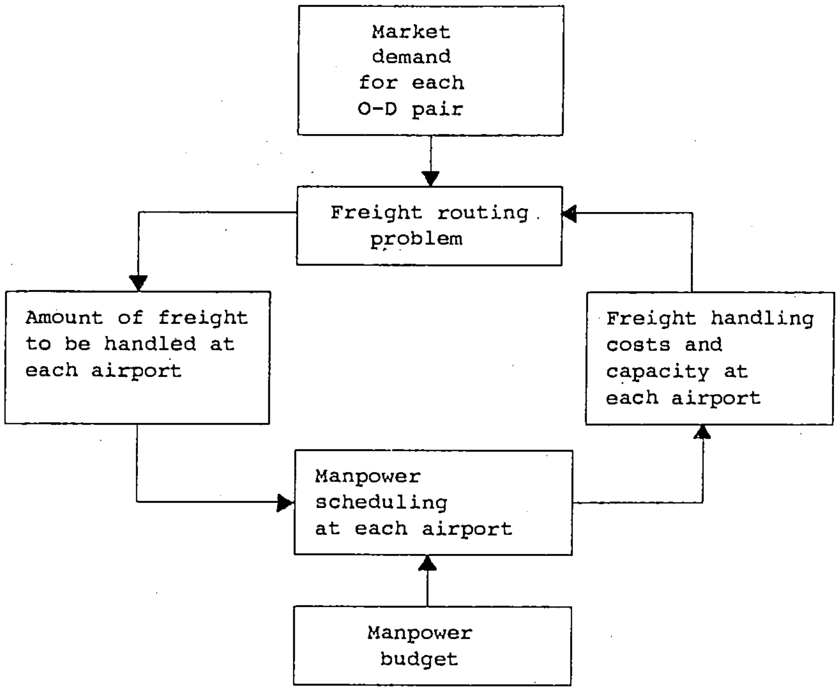


Figure 2: The Relationship Between Freight Routing and Work Scheduling

each traffic class, and capacity constraints that prevent the over-utilization of aircraft cargo capacity for each transportation service, and freight handling capacity at each airport terminal in the network. Decision variables are required to be nonnegative. The trade-offs to be made between operating costs and on-time delivery are explicitly considered at the objective function level. Thus, our model proposes a solution that could provide the best service at minimum cost.

The total system cost is the sum of:

1. the transportation costs, which vary according to the type of services used (fuel consumption, distance travelled);
2. the freight handling costs, which depend on the amount of freight re-handled at intermediate airports;
3. the service penalty costs, which are incurred when service performance standards are not met, considering the planned transit times for each traffic class.

Service penalty costs will vary according to the service level (priority or regular) required by each traffic class. Expected transit times are computed for each itinerary by summing transportation times related to each service (flight segment) used and all delays incurred at each terminal encountered. For the time being, we assume those transit times are deterministic. For a description of how queueing theory can be applied to a similar problem, see the work by Roy (1984).

The modelling structure is as follows:

$$\text{Min} \sum_{m \in M} \sum_{k_m \in K_m} (C^t_{km} + C^h_{km} + C^s_{km}) X_{km}$$

subject to

(i) demand: $\sum_{k_m \in K_m} X_{km} = d_m \quad \forall m \in M$

(ii) capacity: $\sum_{k_m \in K_l} X_{km} \leq A_l \quad \forall l \in L$

$\sum_{k_m \in K_j} X_{km} \leq H_j \quad \forall j \in J$

(iii) non negativity: $X_{km} \geq 0 \quad \forall k_m \in K_m$ and $m \in M$

Where: m is a traffic class (or market), $m \in M$;

l is a transportation service (flight segment), $l \in L$;

k_m is the k^{th} itinerary for traffic class m, $k_m \in K_m$;

X_{km} is the amount of freight routed through k_m (in kilos);

C^t_{km} is the transportation unit cost for itinerary k_m

$$C^t_{km} = \sum_{l \in L_{km}} C^t_l$$

C^t_l is the transportation unit cost for service l;

L_{km} is the set of all services on k_m;

C^h_{km} is the freight handling unit cost for k_m

$$C^h_{km} = \sum_{j \in J_{km}} C^h_j$$

j is an airport terminal in the network ($j \in J$);

J_{km} is the set of all airport terminals on k_m ;

C^h_j is the freight handling unit cost at j;

C^s_{km} is the penalty unit cost for k_m

$$C^s_{km} = C^s_m [\max(0, T_{km} - S_m)]$$

C^s_m is the penalty unit cost for traffic class m;

S_m is the required service standard time for m;

T_{km} is the expected transit time of freight moving on k_m ;

d_m is the demand for traffic class m;

K_l is the set of all itineraries that use service l;

A_l is the cargo capacity of aircrafts assigned to service l;

K_j is the set of all itineraries that go through j;

and H_j is the freight handling capacity available at j.

To solve this problem, itineraries must be generated using a shortest path algorithm where marginal costs are used to measure the "length" of an itinerary. This leads to an arc-chain formulation of a multicommodity flow problem. One of the main characteristics of this formulation is its large size. To solve such a problem, Crainic and Rousseau (1985) have developed an algorithm based on a decomposition approach. We have also examined alternative arc formulations of this problem (Nobert and Roy, 1991) which generate much more variables than the itinerary approach, but also allow for more flexibility in post optimal analyses. The arc formulation approach will not be discussed further in this paper.

3.2. A Solution Approach for the Work Scheduling Problem

We propose a solution approach that will generate work schedules for freight handling employees at air cargo terminals. Our approach is illustrated in Figure 3. First, demand must be determined for a given period of time, e.g. a typical work day. This is done by computing the forecasted amount of freight scheduled to depart or arrive at our cargo terminal per time of day (e.g. every half hour) and for each service class (priority or regular). The result obtained is the amount of freight ready to be handled per time of day. It does not mean that those specific amount of freight will have to be handled at those given times. The specific moment at which freight will be handled depends on the urgency or service class of the freight. Priority traffic will be handled first. But regular freight may be handled over a time interval of a few hours. This allows for some demand levelling to be performed before we turn freight handling requirements into manpower requirements.

Translating demand into manpower requirements is a very delicate matter. Work standards are difficult to obtain because freight handling performance will vary according to various shipments' characteristics such as their weight, the number of pieces per shipment, the handling unit (loose, container, pallet), working methods, terminal configuration and size, and so on. Work standards formulas will therefore have to be adjusted with actual productivity measurements. The result is a histogram representing the number of employees required per time of day, as shown if Figure 4.

The scheduling model is formulated as a linear programming model, where the number of regular and part-time employees starting to work at different (permissible) hours of the day, and the number of overtime hours to be worked are the main decision variables. Their values are determined by minimizing the total (regular, part-time and overtime) labor cost while satisfying the demand as expressed by the number of employee-hours required per time of day. Other constraints are typically found in union agreements and usually restrict the number of part-time employees and overtime hours that can be used. Sometimes, black-out periods, during which a work period is not allowed to

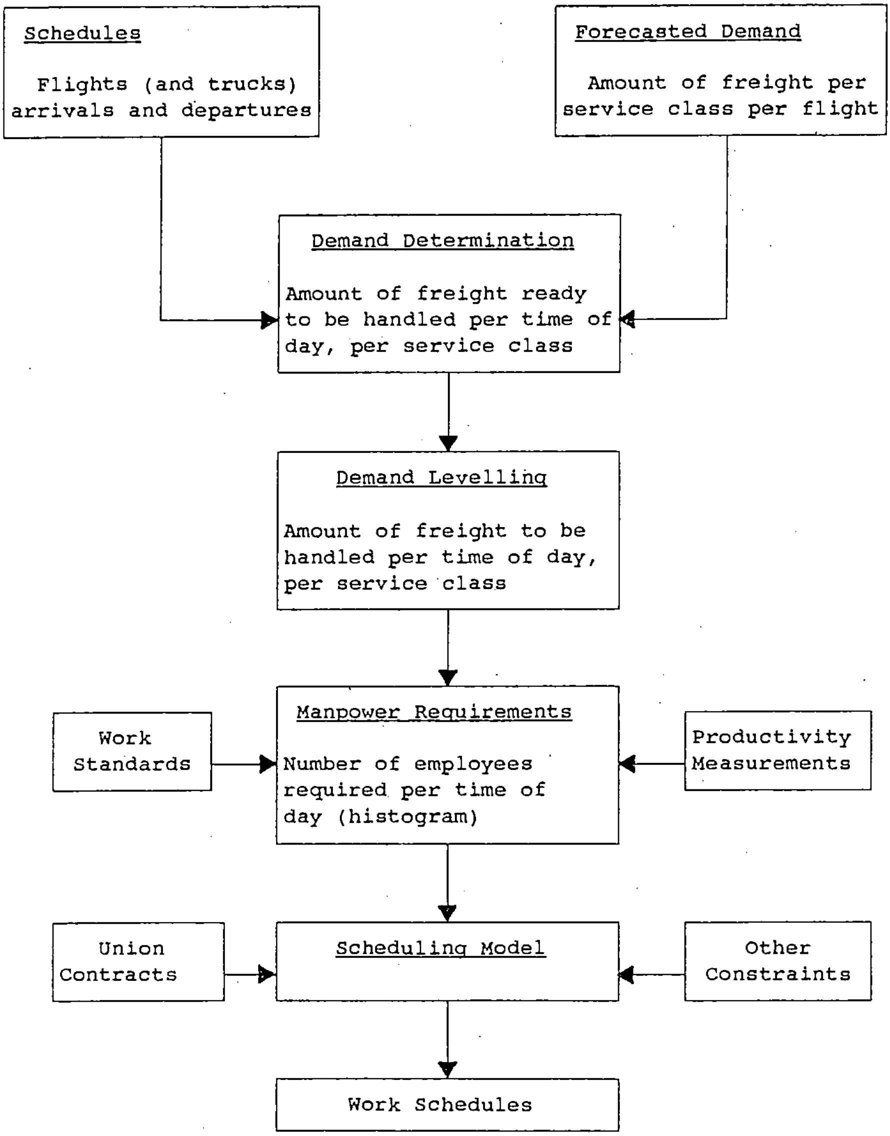
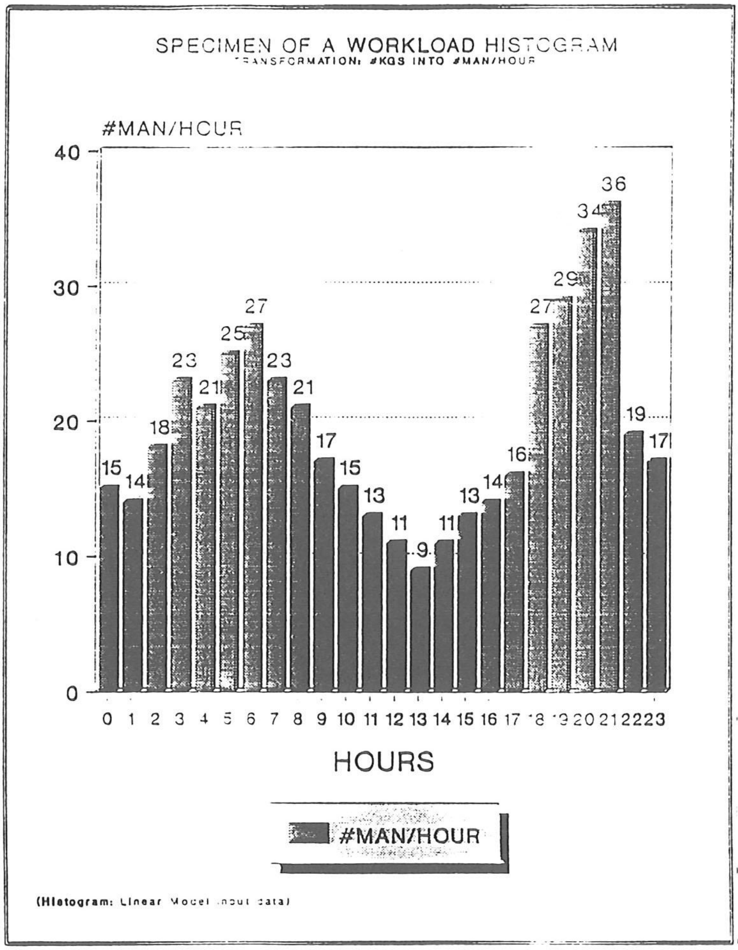


Figure 3: A Solution Approach to the Work Scheduling Problem

Figure 4: Manpower Requirements Distribution Specimen



begin or end, are specified. Finally, budgetary constraints may force an u limit on the number of regular employees available and compromise satisfaction of demand.

3.3. Solving Both the Freight Routing and Work Scheduling Problems

Solving both the freight routing and work scheduling problems simultaneously might sound like a good idea because both problems are located at the tactical level of planning. However, the mere size and complexity of each problem, taken one at the time, makes it difficult enough to solve them successively. Furthermore, the freight routing problem may be thought of as a longer term issue than the work scheduling problem.

In any case, we intend to study the relationship between the two problems by performing post-optimal analyses on both problems. We will first analyze the sensitivity of our work schedules to changes made to the demand inputs, which originate from the freight routing solution. Should the relatively costly work schedules be highly sensitive to freight routing alternatives, then sub-optimization of freight routing may be envisaged as long as the global picture can be improved.

Similarly, sensitivity analyses of freight routing solutions to changes made to freight handling costs and capacity at various air cargo terminals will be performed and the impact of such analyses on the global (total cost of freight routing and work scheduling) picture will be evaluated just the same.

4. CONCLUSIONS

Air cargo operations is a relatively new and exciting field of research. We have begun experimentating our models and solution approaches with actual data provided by Air Canada. The work scheduling problem is of great concern to this airline and our freight routing model should also facilitate the analysis of various scenarios such as:

i) at the strategic level, to determine the amount of space that should be made available on each flight, thereby specifying the aircraft type or configuration, in order to satisfy demand at minimum cost;

ii) at the tactical level, to evaluate the impact of decisions made concerning the freight handling capacity at different airports, on the optimal routing of freight on the network; and

iii) at the operational level, to provide guidance to the management of cargo space on board the aircraft in order to maximize cargo generated revenues.

NOTE

1. In this paper, we use the term "combi" to represent any aircraft that carries both passengers and freight, in spite of the recent trend of using the term "combi" to identify those passenger aircrafts that not only carry freight in their belly compartment but also in a section of the main deck.

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